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Effects of disturbance edges on plant communities and invasive species in a western Montana forest

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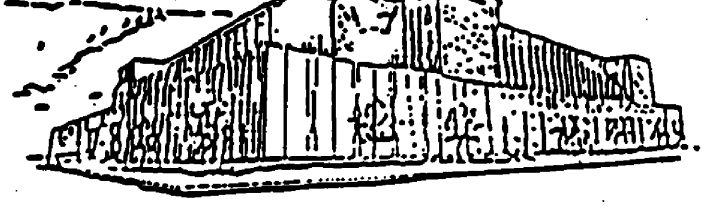

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EFFECTS OF DISTURBANCE EDGES ON PLANT COMMUNITIES AND INVASIVE SPECIES IN A WESTERN MONTANA FOREST

by

Bruce Threlkeld

B.A. Rollins College, 1981

presented in partial fullfillment of the requirements

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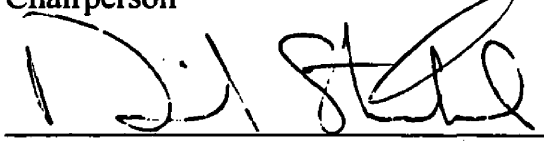

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Effects of Disturbance Edges on Plant Communities and Invasive Species in a Western Montane Forest

Director: Len Broberg

I investigated the effects of disturbance on edge vegetation in a western Montana forest. Forb, herb, and shrub species composition and percent cover were sampled along the edges of 12 randomly chosen sites. 6 sites had been previously modified due to clear cutting and 6 had been disturbed previously by the construction of gravel roads (this comprised the two treatments). Sites were 4080-5100 ft. in elevation, had been disturbed between 10-20 years previous, and were flat to gently sloping. The edges of these disturbances were exposed approximately due north or south. Most plots were sampled underneath *Pinus ponderosa* (PIPO) or *Pseudotsuga menziesii* (PSME) upper-level canopies. Two *Pinus contorta* (PICO) upper canopy sites were also sampled. Ground vegetation communities differed between the field and road treatments. These communities also showed distinctions between upper-canopy types. Noxious invasives were highly associated with road edges. Using Decorana ordination, none of the seven species identified as noxious alien invasives were ordinated closer to the field treatments than they were to the road treatments. Community differences along a depth gradient were found to be insignificant in all cases. However, several noxious invasives (weeds) were found to have unique associations with particular canopy groups, road sites, and the depths at which they were commonly found. Forest managers should consider these associations when planning roads in undisturbed habitat, to avoid potential spread of noxious invasives.

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Introduction

Deforestation, suburbanization, corridor construction, desertification, agricultural intensification, and reforestation have had profound effects on global vegetation (Forman 1995). Two of these land transformation mechanisms are common in Montana: deforestation and road construction, both of which lead to varying degrees of fragmentation. A common feature of habitat fragmentation is a sharp increase in the amount of induced habitat edge (Laurence & Yenson 1991). Edges are considered important landscape elements (Chen, Franklin & Spies 1992) and result in numerous biotic and abiotic changes to the surrounding geographical matrix.

Deforestation creates openings or "gaps" in what was once forested area. These gaps often lead to environmental deterioration in the surrounding matrix. Forman (1995) summarizes several of the potential detrimental effects of edge creation: wind damage—blowdowns and crooked trunks—to trees along newly created borders (induced edges), soil erosion increases, critical changes in the ratio of edge to interior habitat, pest and predator imbalances (source and sink depletion/overpopulation), barriers to abiotic and biotic flows, and aesthetic modification of the landscape. One notable regional occurrence is the recent and often epidemic-scale colonization and infestation of particular noxious exotics—knapweed (*Centaurea maculosa*), sulfur cinquefoil (*Potentilla recta*), and others. Here I use the term "colonize" to indicate few in number and the term "infest" to indicate colonization in large numbers after Forcella and Harvey (1983). Knapweed's effect in open areas such as grasslands and prairies has

been studied (Marcus et al. 1998, Marler 1997, Velagala et al. 1997, Ridenour 1995) but recent forest studies have been minimal (but see Powell et al., 1997), probably due to a lack of heavy infestation in these environments. Potential impacts of invasives developed on the basis of studies in grassland communities may not be applicable to forest communities (Losensky 1987). Weeds generally occupy dry open sites (Lindsay 1953, Salisbury 1961). However, many noxious exotics are invading forests. Ponderosa pine stands in western Montana have been shown to contain invasives (Forcella and Harvey 1983, Losensky 1987, Bedunah and Carpenter 1991) but cooler moister habitat types such as *Abies lasiocarpa* and *Pseudotsuga menziesii* have shown few colonizations of weeds (Forcella and Harvey 1981). There are few recent studies of noxious invasives in Montana forests.

Roads are often associated with open gaps created by deforestation. Frenkel (1970) lists ecological modifications that are attributed to corridor construction including treading, soil compaction, confined drainage, increased run-off, removal of organic matter and sometimes additions of litter or waste material of frequently high nitrogen content (including urine and feces), mowing or crushing of tall vegetation, herbicide application, removal of woody vegetation but occasionally the addition of wood chips or straw, substrate maintained in an ecologically open condition by blading, intensified frost action, rill and sheetwash erosion, snow deposition, and a host of other conditions associated with paving (note: all roads in this study were unpaved forest service roads, with gravel beds). He points out that not all roads will demonstrate all of these alterations, yet in varying degrees these diverse disturbances may influence the linear pattern of environmentally differentiated zones which are oriented parallel to the

road axis. Numerous studies have been published on the adverse impact of roads on mammals (Oxley et al. 1974; Mader 1984; Adams and Geis 1983; Garland and Bradley 1984; Swihart and Slade 1984; Bennett 1991; Brody and Pelton 1989), but fewer studies have been published on the effects roads have on vegetation, especially in the Northwest (Forcella and Harvey 1981).

Parameters of edge effects that have been studied include: Microclimatic variables, including wind velocity, solar radiation, soil temperature, litter moisture, and relative humidity (Chen 1991, Matlack 1993), vegetation structure and floral composition (Ranney et al. 1981, Lovejoy et al. 1983, Chen et al. 1990), tree mortality (Alexander 1964, Wales 1972), tree regeneration (Gysel 1951, Caruso 1973, Wagner 1980, Williams-Linera 1990), and stem density and basal area (Gysel 1951, Wales 1972, Caruso 1973, Ranney et al. 1981). Most edge vegetation studies have focused on woody species and as a consequence little is known about the impact of creating edges on the community as a whole, or how edge communities may change over time (Matlack 1994). Studies focusing on shrub, sub-shrub and forb composition, structure, and associated mechanisms are lacking, both regionally and nationally. In order for management to implement successful land conservation strategies in Montana forests, it is important to understand the scale and magnitude of disturbance along edges. Contrary to popular notion, probably started with Leopold's (1933) observation of greater wildlife diversity at edges, the circumstantial evidence for the positive aspects of edge effects has been debated in recent years (Yahner 1988). I investigated changes in plant abundance and community composition along the edges of two different disturbance regimes, those resulting from forest service road construction and those created by clear-cuts. The

questions I pose are: 1. Do plant communities differ between road and field edges? and 2. How deep into the forest interior do these proposed differences extend? The questions are answered by quantitatively measuring biotic and abiotic components of the edges and statistically comparing the results. This study focuses mainly on invasive species, with a particular emphasis on the ecology at the shrub level of scale.

I chose a floristic approach to describe individual species—their distribution and assemblage, and an ecological approach to detail community aspects—environmental relationships such as total plant cover and inter-species associations. The floristic approach is tested primarily by univariate methods while community relationships are evaluated using ordination techniques.

"Invasives" typically: (1) are uncommon in their native habitat; (2) have high reproductive output; (3) are easily dispersed short distances; (4) are phenotypically plastic (wide tolerance or generalist species); (5) and have fast growth rate. Two important environmental conditions of an edge—disturbed ground and open upper canopy—are intrinsic characteristics of an ecosystem prone to invasive establishment.

The current political tenor in the United States regarding issues effecting the nations resources—particularly the recent presidential mandate charging the Forest Service with the task of evaluating thousands of acres of roadless areas—makes this type of study timely. The vectors (by which invasives spread) of disturbance are important to delineate, in order for management to make accurate analyses and prescriptions for forest ecosystem health.

Methodology

Study Area

Lubrecht Experimental Forest is a 23,000 acre (9300 ha) research facility of the University of Montana School of Forestry located about 30 miles (48 km) east of Missoula Montana and approximately 50 miles (80 km) west of the Continental Divide. The area is climatically between the range of the maritime climate to the north and west, and the drier region to the south and east. Elevation ranges from about 4000 to 5500 feet (1200-1675 m). Annual precipitation varies, but an approximate range is between 12 and 30 inches (31-76 cm) per year (Steele 1980). Precipitation amounts are heavier in the higher elevations. With the exception of isolated areas of scree slopes, rock outcrops, and riparian zones the majority of Lubrecht is capable of supporting forest vegetation. The study area is primarily mountainous terrain typical of mid-elevation (~4200 ft.) coniferous forests of western Montana. Dominant tree species at Lubrecht include: Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), and western larch (*Larix occidentalis*). Other species include Engelmann spruce (*Picea engelmanii*), subalpine fir (*Abies Lasiocarpa*), and two deciduous species, quaking aspen (*Populus tremuloides*) which is usually confined to regeneration areas, and black cottonwood (*Populus trichocarpa*) which is often associated with riparian zones.

Most of Lubrecht is second-growth forest. Logging began around 1905. It was continued during the period 1925-1934, when railroad spur lines were built up Elk Creek, North Fork Elk, and Stinkwater Creek (Cauvin 1961, and Steele 1964). The early logging practices removed only the largest merchantable timber and left many

trees which have since become dominant overstory trees. This has resulted in many stands having a clumpy, uneven appearance, with a scattering of older dominant trees interspersed with lower stories of emerging poles and saplings in various densities. In other areas the lack of cultural treatments has resulted in stands with erratic overstory patterns and size distributions, even though the age distribution may be rather uniform (Teuber 1983).

Sampling scheme

I have conducted a *sample survey* (Cox and Snell 1981). Twelve edges (sites) were initially selected for the study, according to the following criteria: elevation 4600 ft. +/- 500 ft.; slope < 10 degrees; orientation, due north (6 sites) and due south (6 sites), +/- 30 degrees; relatively homogenous canopy cover for >100 m; relatively homogenous and undisturbed ground cover for >100 m; age of field or road bordering treatment edge—10 to 20 years (cuts made between 1981 and 1990).

Two treatments—forest-road edges and forest-field edges—each containing six sites, were studied. In order to account for potential microclimatic differences between northern-exposed edges and southern-exposed edges (particularly available photosynthetic radiation) each of the six sites were further divided into three edges facing south and three edges facing north. Areas with homogenous canopies to a depth of at least 100 m were selected to avoid gaps or open areas. 14 samples (plots) were discarded due to gap areas (>20 m diameter circle) to eliminate the potential influence of gap dynamics on the study. Sampling was carried out during the late summer of 1999. Total area sampled was 240 m^2 (= 240 individual 1m^2 plots). Sampled plants include forbs, shrubs, and sub-shrubs, with densities estimated by canopy coverage (using 1m^2

quadrats). Vegetation was measured to the species taxonomic level, although identification of some *Rosa, Aster, Antennaria, Penstemon*, and *Vaccinium* were limited to genus, due to wilted and unrecognizable foliage conditions.

Upper canopies of the twelve treatments consisted primarily of *Pseudotsuga menziesii* (PSME), *Pinus ponderosa* (PIPO), and *Larix occidentalis* (LAOC), with PSME and PIPO dominating most sites. Two sites (1 and 4, see Table 4) were dominated almost exclusively by *Pinus contorta* (PICO).

Soil structures typically associated with PSME/PIPO at these elevations in Lubrecht are derived from limestone parent material, although granitic and quartzite-derived soils may also be found. Soil profiles are sometimes important indicators of vegetation response and community interaction, however, soil classification systems are not primarily designed to reflect influences on vegetational development (Pfister et al. 1977).

Sites were chosen so that ecotones (defined here as a "soft edge" or natural gradient, as compared to an anthropogenically-created sharp border), gaps, roads and clear cut areas within the sampling area were minimized. Edges ranged in length from 88 m to a maximum of 150 m. In this paper I define "edge" as a boundary line between a disturbed open area and the adjacent forest, and I defined "depth of edge influence" (or edge width) as a transition zone in which the adjacent contrasting ecosystems of clear-cut and forest interact (Chen, Franklin, and Spies 1992). More specifically, in this study, the term "forest-field edge" is used to indicate a transition zone from the forest (where all sampled plots have been located) to a clear-cut field; "forest-road edge" denotes a transition zone from the forest to the edge of a road. No samples were taken

in the actual fields that border the forest under study, and likewise, no plots were established on any roads. All sampling was done in the forests that bordered these clear-cuts and roads. The measurement of edge width is arbitrary depending on the variable of interest, timing of measurement, and the approach used for calculation (Chen 1991). In this study I chose to measure depth effects to a relatively shallow distance of 50 meters into the forest, since a major focus was on invasives which tend to infest disturbed open sites (i.e. shallow interior penetration) in western Montana (Forcella and Harvey 1983). Hence, the depth of edge influence is defined here as a 50 meter-wide strip that runs from the "true edge" of the forest at 0 meters, perpendicularly into the forest to a depth of 50 meters. This 50 meter wide area will also be referred to simply as the edge. See Fig. 5 for a detailed illustration of a typical site. A random starting point was chosen along the true edge (0 meters), and five evenly spaced (10 m or 20 m apart, depending on the total length of the edge) transect starting points were selected. Using this scheme guaranteed that a representative portion of the edge had the potential to be sampled. If a random number generator were used instead to select transect placement along the edge, there would be a possibility of clumping at one end.

Lengths of transects were 50 m (the edge width). This necessitated a continuous 100 meters of anthropogenically-undisturbed canopy and ground to qualify as a true edge (50 m into the forest and at least 50 m out towards the opposite edge if one existed, so that the 50 m station reading would not be any closer than 50 m to any opposing border). Lengths of 100 m or more were difficult to locate because of the disturbance history at Lubrecht. Since the study was designed to measure understory communities and particularly noxious invasives which tend to colonize open areas (Kennett *et al.*

1992; Watson and Renney 1974, Forcella and Harvey 1983), 50 meter transects were used.

A 1 m^2 square quadrat was used at each of the sampling locations (plots). Plots were located at the following depths along the transects: 0 m, 10 m, 25 m, and 50 m, giving a total of 4 depths each with 5 plots. Total stations for each site equaled 4x5 = 20. Abundance was measured as vegetation cover percentage to the nearest 1 percent.

DECORANA (DCA) detrended correspondence analysis was used in all analyses unless otherwise noted (Jongman et al. 1987). SPSS software (SPSS® Base 8.0) was used to perform Kruskal-Wallis tests to determine if depth into the forest affected mean species abundance.

Results

A list of all noxious unvasive species sampled in this research is given in Table 1. I have highlighted the designation of certain plants according to *Weeds of the West* (Whitson et al. 1999).

DCA gradient analysis yields figures with axes that provide a relative gradient along which samples are separated on the basis of species composition primarily based on the x-axis position. For instance, in Fig. 1. note that *Centaurea maculosa* (Cenmac) is located far to the right of the graph, with an x-axis value of 444 and a y-axis value of 228 (see Table 1 for x-y values of all noxious species). The majority of road sites (red circles) appear to the right of the figure and the field plot centroid shows less association with species on the right of the figure (placing it to the left of the average road plot). This shows that the typical *Centaurea maculosa* plant is more associated with road plots than field plots. Note that in Fig. 1 the majority of noxious invasives appear to be

associated with road plots. Table 3 lists the five most significant species for the ordination.

A total of 206 plots (94 field, 112 road) were sampled using ordination techniques. One site (#6) was disgarded for community analysis, due to unusual characteristics. It was located within about 25-50 meters of a road and may have been more similar in composition profile to road sites: it was the only field site that contained *Centaurea maculosa* and it was the only site to contain entirely ponderosa pine—upper and lower canopy. A lower ponderosa pine canopy may have been indicative of a recent unrecorded disturbance event, which would have biased the field samples. Removing this site did not result in any significant changes in associations between noxious invasives and treatment type (road or field).

The distinction between forest edge communities along roads and those along fields can be seen in Fig. 1. There is a separation, highlighted by centroids, between these two communities. The species distribution indicates two major noxious invasive species, *Centaurea maculosa* and *Potentilla recta*, shifted towards an association with road plots.

Zero meter plots of the forest-road edges and forest-field edges (Fig. 2) differed, supporting the hypothesis that the two communities differ specifically at the true edges (0 m) of the treatments. Only three of the total (seven) noxious invasives were found at this depth, and they are all associated with road plots, particularly *Centaurea maculosa*, which is farthest to the left of the ordination.

When the interior (10m to 50m plots) were combined by treatment, a significant separation was established according to the analysis (Fig.3). Hence, I found no evidence

to support homogeneity (overlap) of community composition at the interior of these two treatments.

Additional ordination tests included north-facing edges versus south-facing edges to determine if there were community differences due to available photosynthetic radiation. Suprisingly, in each treatment, no significant community variations were found (i.e. north facing road and south facing road communities were not significantly different according to DCA analysis), however, the sites comprising the southern orientation field group were different from both northern and southern road groups.

Individual species

Two species totalled 95.9% of the overall noxious species abundance and 86.6% of the frequency according to Table 1. These two—*Potentilla recta* and *Centaurea maculosa*—were by far the two most common alien noxious invasives (Table 2).

Symphoricarpos albus had the highest frequency of any shrub/forb species (found in 161 of 206 plots, see Table 2, column S); *Centaurea maculosa* was found in 28 plots. *Centaurea maculosa* ranks 8th overall, *Potentilla recta* 7th in abundance. Along with *Potentilla recta*, *Centaurea maculosa* forms the majority of the noxious alien invasives, and it is the only species sampled found to have a correlation with edge depth. *Centaurea maculosa* decreases significantly with depth into the forest. Although *Centaurea maculosa* was high on the species abundance list and was shown to be significantly correlated with depth into the forest, *Potentilla recta* could not be explained by depth.

Canopy comparisons

Plots were also examined according to the species composition of the canopy cover. Of the 12 sites sampled overall, 2 sites were classified as lodgepole pine (PICO), 3 sites were classified as ponderosa pine (PIPO), and 7 sites listed as Douglas-fir (PSME). 3 of these Douglas-fir sites had an equal number of ponderosa pine trees as well. Ordination results are illustrated in Fig. 4. *Pinus contortus* plots appear to run diagonally up to the left from center, *Pinus ponderosa* plots are grouped towards the right, and *Pseudotsuga menziesii* plots tend towards the lower left of the figure. The centroids show the confidence intervals at a 95% level, with a significant distinction between all three groups. Also of interest is the location of species when overlapped on the plots (not shown). *Centaurea maculosa* and *Potentilla recta* are associated with *Pinus ponderosa* canopies at the far right end of the figure, similar to their position in Fig. 1. Since the *Pinus ponderosa* canopies (Sites 9 and 12) were open, and likely drier and warmer than the other two main groups of canopies, invasive colonization and infestation is not surprising.

Discussion

The most significant finding was that alien invasive plants favored establishment associated with road plots (Figures 1, 2, and 3). Few alien invasives were found in the forest-field plots. Although caution must be used when investigating causes for the separation of road and field edge plots into distinct groupings, one can see from Fig. 1 that five species designated as noxious (see Table 1) are ordinated towards the right side of the graph (associated closer to the forest-road plot centroid), and that the other two are approximately equidistant from the two centroids. None of the noxious plant species show an affinity for being associated more with field plots than with road plots. This

lends support to the hypothesis that these species may prefer to infest roadsides more frequently than clear-cut field edges. The ages of these sites were approximately equal, meaning that seed dispersal time would be the same. Vectors of dispersal (likely vehicles primarily) were probably involved with the more rapid spread of certain invasives along roads, but it is odd that virtually no major noxious invasives were found in five of the six field edges. Further studies on individual species may be helpful in ascertaining the specific ecological traits of these plants and their interaction with forest edges.

I found little support for variation in the communities with depth. However, *Centaurea maculosa*, showed a high level of association with the true edge (0 m) of road plots ($p<0.01$, Kruskal-Wallis), and was not found in 5 of the 6 field plots. The absence of distinct groups along a depth gradient seems unusual since we would expect invasives to occupy territory along the borders of fields (more light and higher disturbance) rather than interior plots, thus causing a shift in the community vegetation as one samples deeper into the forest. The species often do segregate in such a manner, however, the high abundance of native species such as *Symphorocarpos albus* could have overshadowed the effect that the less populated invasive groups may have had on the ordination process. In any case, the ordination analyses, which relies on species abundance and frequency as a means of distinction, may understate the effect that the invasive communities may be having on native populations.

Traditionally, invasives are found at open, disturbed sites, however *Potentilla recta* has shown a tendency, in this environment, to be capable of penetrating deeper than the true edge of both of these types of disturbances. This is especially noteworthy

given the density of this species. Interior forests that have been opened up by disturbance may be prone to deeper depth penetrations and wider spread of this invasive compared to *Centaurea maculosa.*

The consistently high abundance among sites of *Symphorocarpos albus* appears to contradict Losensky's (1987) premise that PSME/SYAL communities are threatened by knapweed, although without knowing the exact disturbance regime over the past 15 years this is difficult to verify. Future studies could address this question more directly.

Future studies could involve several PICO sites on the edges of roads, which would have been useful in assessing canopy cover comparisons. Would a triangular spread (Fig. 4) remain if PICO road sites were available? Perhaps the ordination would then be a bit more ambiguous. And if road/field comparisons remained distinct, perhaps road/field differences were driving the ordination more so than upper canopy cover types. Previous studies have shown presence of *Centaurea maculosa* in western ponderosa pine stands (Bedunah and Carpenter 1991, Forcella and Harvey 1983). This study only looked at stands on flat terrain, zero to ten degrees slope with northern or southern exposures. Future studies could also sample slopes with different exposures, and associated varying moisture levels. Hydrologic and edaphic factors could play a role in the establishment of noxious invasives. This research did not address these possibilities.

Management Implications

Centaurea maculosa colonizes and infests large areas of western Montana prairies and grasslands. However, studies are lacking on its capacity to do the same to Montana's forest ecosystems. This study revealed that spotted knapweed, sulfur cinquefoil, Canada goldenrod

cinquefoil, Canada goldenrod (*Solidago canadensis*), and Canada thistle (*Cirsium arvense*) have the potential to spread along forest roads, and that they prefer to be associated with this type of disturbance, even when open field edges are in close proximity. Some road plots were only 10 years old, yet the current population is large (see totals in Tables 1 and 2). Management should consider these results when planning roads in undisturbed habitat. The positive side of knapweed infestation is that it appears to have limited penetration capabilities. Therefore, it appears to be constrained to whatever disturbed habitat is available, though in this study it did not appear to spread to neighboring field edges. This is not the case apparently with *Potentilla recta* which established significant populations as far as 50 meters into the interior of the forest. This species was also not associated with many forest-field plots.

Acknowledgements

I wish to thank Len Broberg, Paul Alaback, and Ray Callaway, for their counsel during the preparation and execution of this study. Their assistance was invaluable, and I am grateful to have had these dedicated faculty members serve on my committee. Also, thanks to Peter Stickney for helping to identify species found in the research.

Figure 1

road edge communities versus field edge communities

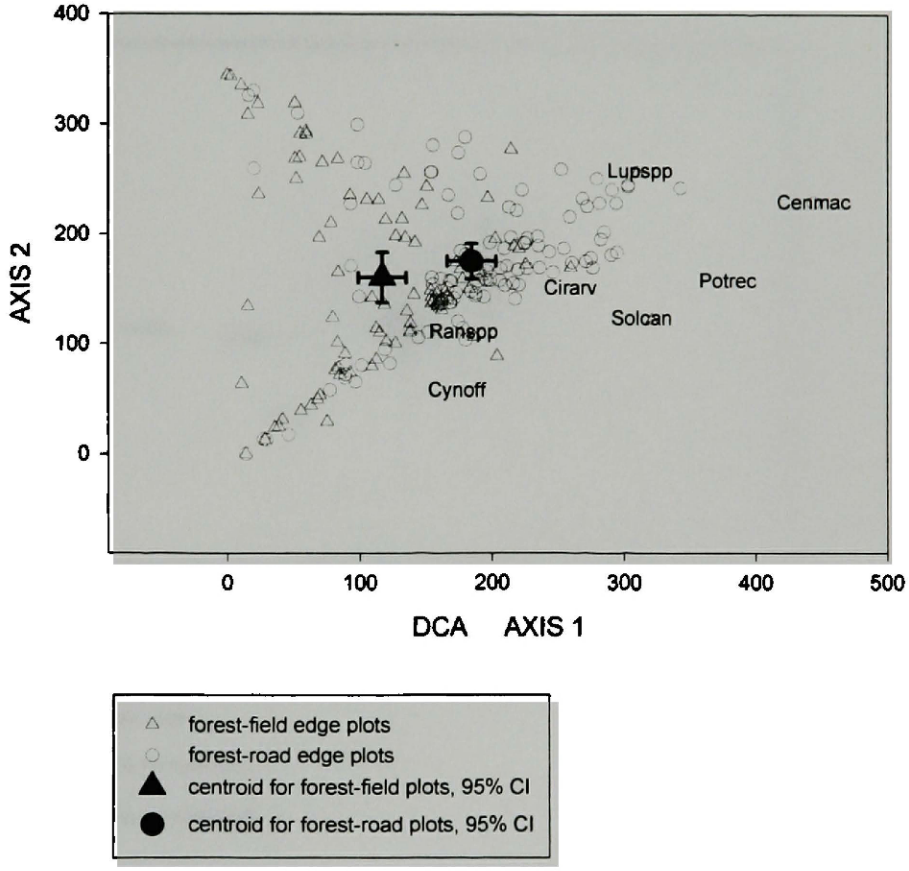

Figure 1 shows combined plots (all depths) that were along roads (red circles) and those along field sites (green triangles). The centroids of each of these types of edge communities are designated by the larger circle and triangle (at a 95% confidence interval). Also listed are several noxious invasive plants. Of these, Category One Weed species include *Potentilla recta* and *Centaurea maculosa*, which show the greatest tendency towards association with road sites.

Figure 2
true edge (0 meters) comparison
road edge communities versus field edge communities

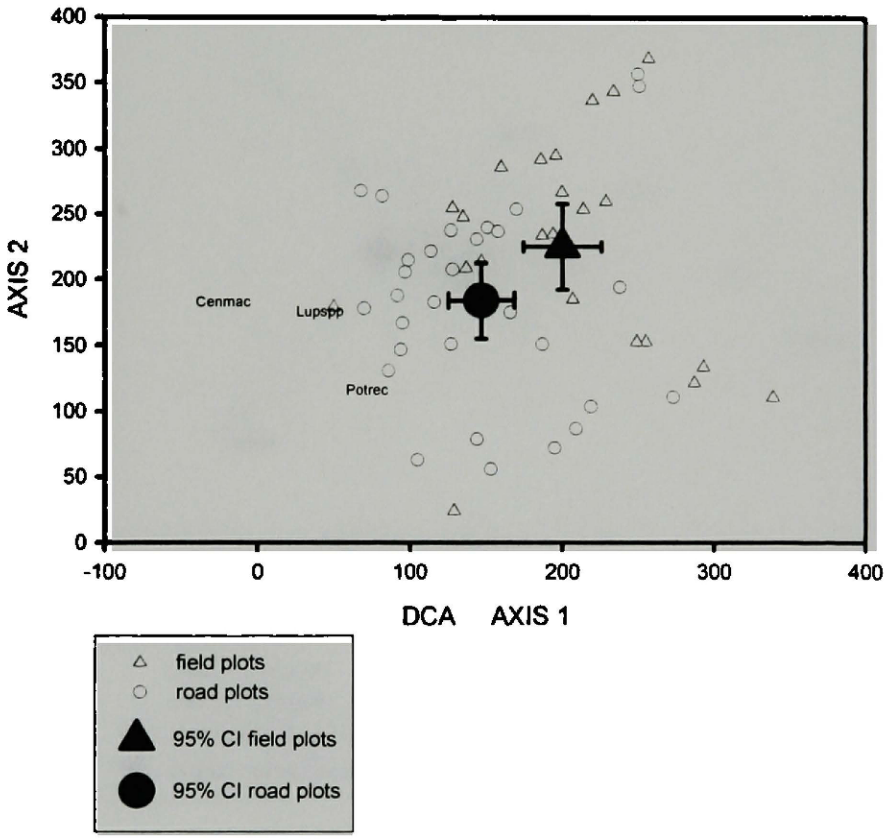

Figure 2 shows only those plots where the forest edge meets the road or field (depth = 0 meters). We note a clear separation on the x-axis between the two types of disturbances, as exhibited by the non-overlap of the centroid error bars at a 95% confidence interval. This supports the hypothesis that there are distinct communities between forest edges bordering roads and those bordering fields, at 0 meters depth. *Centaurea maculosa* and *Potentilla recta* are associated again with road plots.

Figure 3
comparison of interior plots
road edge communities versus field edge communities

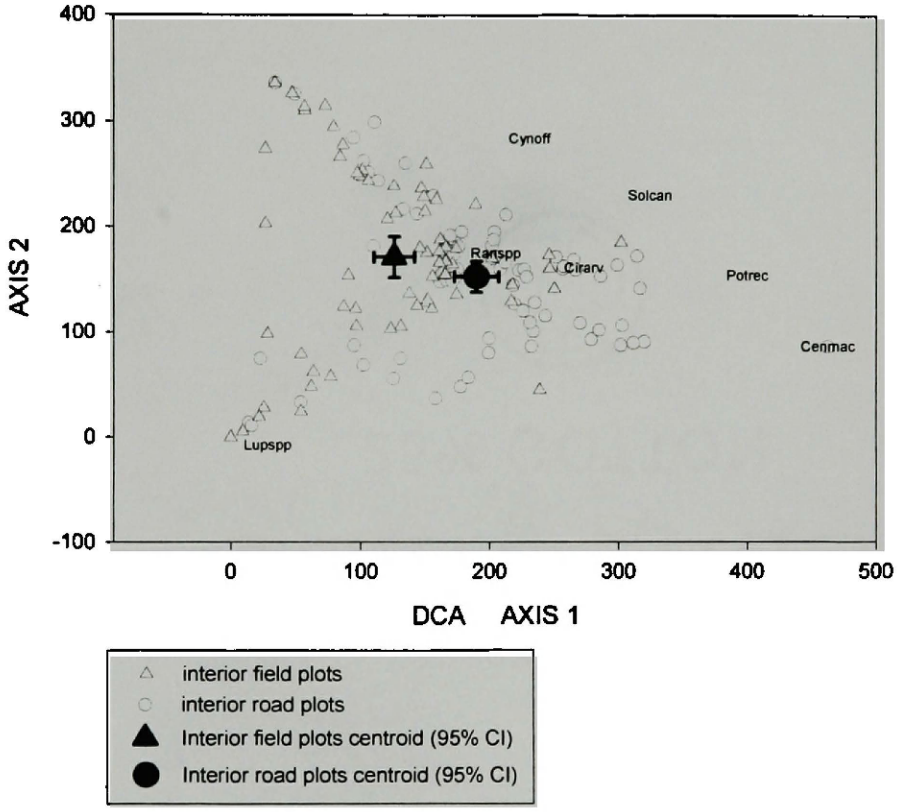

Figure 3 shows all interior plots, measured at 10 meters, 25 meters, and 50 meters, of the respective sites--field edges and road edges. Here we no overlap of the error bars (95% CI) on the two centroids, indicating variation between road and field edges with respect to interior plots. Note that *Centaurea maculosa* and *Potentilla recta* are associated again with road plots.

Fig.4
Canopy comparisons

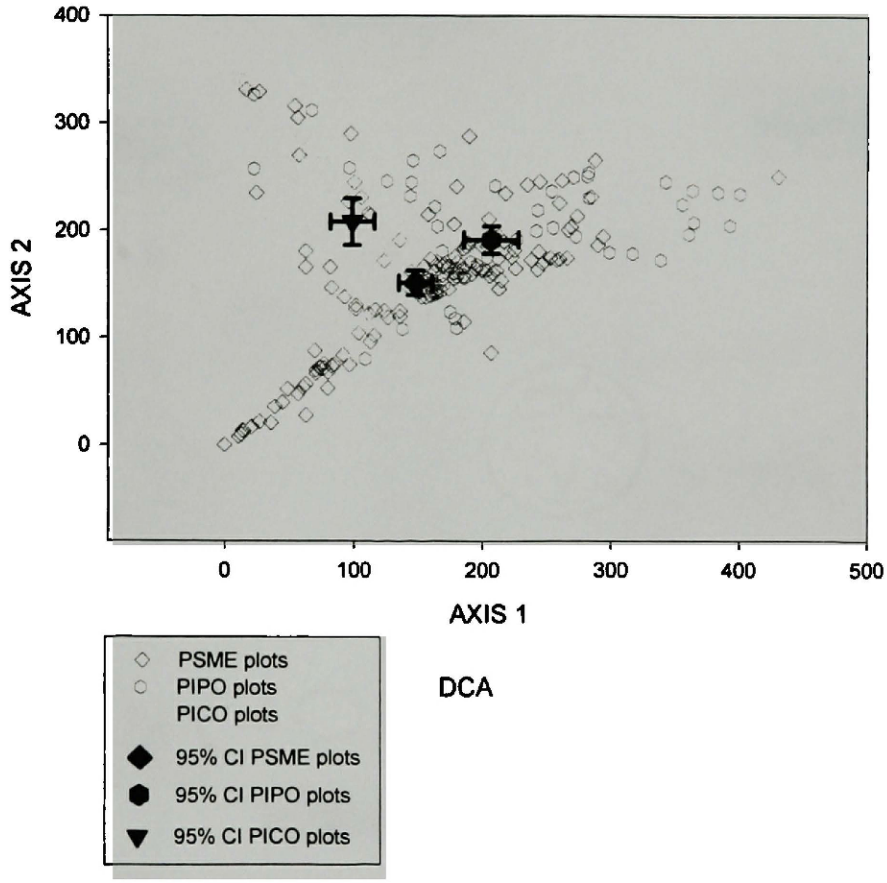

Figure 4 is an ordination of all plots grouped by major upper canopy type. The Douglas-fir plots (PSME) tend towards the lower left, while ponderosa pine (PIPO) and lodgepole pine (PICO) are grouped to the upper right and left respectively. Note the clear distinction in the centroids at a 95% confidence level, indicating a clear separation of ground vegetation according to upper canopy type.

Fig. 5
TRANSECT PLACEMENT
Typical field site (e.g. #4)
Northern orientation

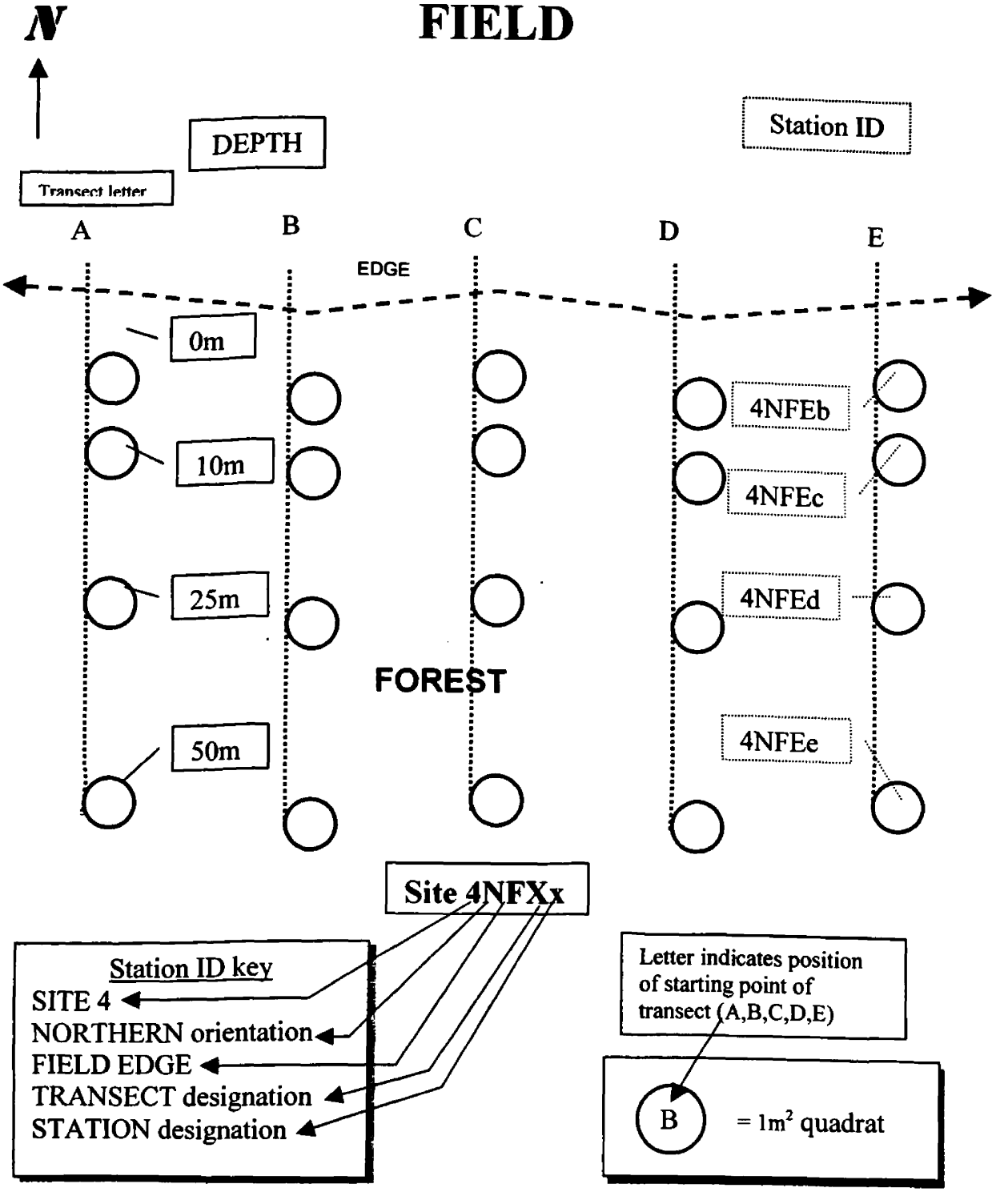

Table 1

BIODIVERSITY of NOXIOUS INVASIVE SPECIES

Noxious species comprised 7.1% of total community cover. Invasives typically (1) are uncommon in their native habitat; (2) have high reproductive output; (3) are easily dispersed short distances; (4) are phenotypically plastic (wide tolerance or generalist species); and (5) have fast growth rate.

SPECIES	Abundance %	Frequency %	x-y coordinates for Fig. 1.
Cenmac*	42.5	32.1	444,229
Cirarv*	0.5	2.9	259,151
Cynoff*	1.5	1.9	174,58
Lupspp	1.5	4.9	312,258
Potrec*	53.4	54.5	379,157
Ranspp	0.2	1.9	179,111
Solcan	0.4	1.9	314,123
TOTALS	100	100	

Abundance = Σ individual species ground cover / Σ total noxious species ground cover.
Frequency = # of plots where individual species is found / total # of plots containing at least one noxious specie.
2 most abundant spp: Potrec and Cenmac = 95.9% of noxious invasives.
* signifies noxious alien plant.

Table 2

Species summary

Name		Mean % cover	Stand.Dev.	Sum - Cover	Min %	Max %	S
Achmil	*Achillea millefolium*	0.867	2.233	196	0	20	87
Anespp	*Anemone genus*	0.009	0.133	2	0	2	1
Antspp	*Antennaria genus*	4.265	10.97	964	0	68	87
Arcuva	*Arctostaphylos uva-ursi*	5.336	15.069	1206	0	95	60
Astspp	*Aster genus*	3.358	8.366	759	0	60	100
Berrep	*Berberis repens*	4.257	7.041	962	0	50	130
Casmin	*Castilleja miniata*	0.044	0.665	10	0	10	1
Cenmac	*Centaurea maculosa*	2.642	12.147	597	0	90	28
Chiumb	*Chimaphila umbellata*	0.058	0.681	13	0	10	3
Cirarv	*Cirsium arvense*	0.035	0.409	8	0	6	3
Collin	*Collomia linearis*	0.066	0.998	15	0	15	1
Cradou	*Crataegus douglasii*	0.044	0.665	10	0	10	1
Cynoff	*Cynoglossum officinale*	0.088	0.939	20	0	10	2
Erygra	*Erythronium graniflorum*	0.035	0.208	8	0	2	7
Fravir	*Fragaria virginiana*	1.274	2.738	288	0	30	97
Galspp	*Galium genus*	0.323	1.466	73	0	15	23
Gerspp	*Geranium genus*	0.049	0.483	11	0	7	5
HeuCyl	*Heuchera cylindrica*	0.097	0.618	22	0	6	9
Hiespp	*Hieracium genus*	0.15	0.757	34	0	8	15
Linbor	*Linnea borealis*	0.553	5.659	125	0	75	4
Litrud	*Lithospermum ruderale*	0.133	1.24	30	0	15	3
Lupser	*Lupinus sericeus*	0.058	0.443	13	0	5	6
Lupspp	*Lupine genus*	0.088	1.012	20	0	15	5
Luzcam	*Luzula campastris*	0.004	0.067	1	0	1	1
Penspp	*Penstemon genus*	0.695	2.54	157	0	20	33
Pergai	*Perideridia gairdneri*	0.031	0.345	7	0	5	3
Potrec	*Potentilla recta*	3.319	11.137	750	0	80	47
Potspp	*Potentilla genus*	0.08	0.414	18	0	3	10
Ranspp	*Ranuncula genus*	0.018	0.21	4	0	3	2
Rosspp	*Rosa genus*	1.482	4.018	335	0	35	65
Sedste	*Sedum stenopetalum*	0.049	0.391	11	0	4	4
Solcan	*Solidad canadensis*	0.022	0.239	5	0	3	2
Spibet	*Spirea betulifolia*	4.81	11.103	1087	0	60	73
Symalb	*Symphorocarpos albus*	13.938	17.156	3150	0	90	161
Thaocc	*Thalium occidentalis*	0.239	1.525	54	0	20	15
Trirep	*Trifolium repens*	0.885	3.923	200	0	40	26
Triagr	*Trifolium agrarium*	0.004	0.067	1	0	1	1
Vacspp	*Vaccinium genus*	2.004	7.704	453	0	70	31
Vioorb	*Viola orbiculata*	0.031	0.289	7	0	4	4
Dodcon	*Dodecatheon conjugens*	0.004	0.067	1	0	1	1

S = frequency = number of plots where species was found (total plots = 206).

Table 3

top 5 species rankings at 0m depth
by r-squared values

Species	Treatment	r-sq.value	frequency	mean abund. %	std.dev
Spibet	field	0.59	13	6.00	8.92
Arcuva	field	0.47	10	8.88	20.25
Rosspp	field	0.17	11	0.72	0.98
Vacspp	field	0.14	5	1.32	3.58
Trirep	field	0.12	2	0.16	0.62
Spibet	road	0.54	4	3.93	14.00
Cenmac	road	0.24	11	2.70	5.87
Vacspp	road	0.21	4	3.47	13.71
Penspp	road	0.15	10	1.67	4.20
Litrud	road	0.13	1	0.50	2.74
Lupspp	road	0.13	1	0.50	2.74

R-squared values are measures of significance to the ordination
Species are listed according to highest r-squared values
Frequency numbers for field are based on a total of 30 plots
Frequency numbers for road are based on a total of 25 plots
Top 5 ratings (based on r-squared values) are given for each treatment
For a full species list see Table 2

Table 4

Site information

SITE ONE, SF1:

Township 13 North, Range 15 West, sec 12, elevation 4100 ft., edge cut 1982
Southern orientation @ 220°, aspect = 0, slope = <5°, edge length = 111 m.
Upper canopy: PICO dense, middle-lower canopy: none. Sampled: 9/2,7,8/99
Comments: *this area is known as the lodegpole thinning demonstration area in Lubrecht, and is one of only two sites in the study not dominated by PIPO or PSME. Site* NF4 *is the complementary site (opposite orientation) to this site*

SITE TWO, SF2:

Township 13 North, Range 14 West, sec 19, elevation 5100 ft., edge cut 1985
Southern orientation @ 172°, aspect =S, slope = ~5°, edge length = 150 m.
Upper canopy: PSME/LAOC , middle-lower canopy: none. Sampled: 9/14/99
Comments: *this site has the highest elevation of those sampled and has no complementary northern orientation site.*

SITE THREE, SF3:

Township 13 North, Range 15 West, sec 13, elevation 4200 ft., edge cut 1982
Southern orientation @ 202°, aspect =0, slope = <5°, edge length = 110 m.
Upper canopy: PSME/LAOC few PIPO, middle-lower canopy: PSME. Sampled: 9/20/99
Comments: *an old logging road ran diagonally to the sampled area, some plots were disgarded due to this gap. Complementary plot is* NF5.

SITE FOUR, NF4:

Township 13 North, Range 15 West, sec 12, elevation 4100 ft., edge cut 1982
Northern orientation @ 25°, aspect =0, slope = <5°, edge length = 88 m.
Upper canopy: PICO, middle-lower canopy: none. Sampled: 9/8,9/99
Comments: *this is the complement to site* SF1, *and has similar characteristics.*

SITE FIVE, NF5:

Township 13 North, Range 15 West, sec 13, elevation 4200 ft., edge cut 1982
Northern orientation @ 28°, aspect =0, slope = <5°, edge length = 88 m.
Upper canopy: PSME/LAOC few PIPO, middle-lower canopy: PSME. Sampled: 9/21/99
Comments: *this is the complement to site* SF3, *and has similar general characteristics. There was a small Populus tremuloides grove located within this treatment though no unique species were found.*

SITE SIX, NF6:

Township 13 North, Range 15 West, sec 12, elevation 4080 ft., edge cut 1982
Northern orientation @ 28°, aspect =S, slope = ~5°, edge length = 90 m.

Upper canopy: PIPO open, middle-lower canopy: PIPO. Sampled: 9/27/99
Comments: *this is one of the more open sites, typical of ponderosa pine stands.*

SITE SEVEN, SR7:
Township 13 North, Range 15 West, sec 24, elevation 5000 ft., edge cut 1986
Southern orientation @ 178°, aspect =NW, slope = ~5°, edge length = 140 m.
Upper canopy: PSME sparse, middle canopy: PSME/PIPO thick. Sampled: 9/21/99
Comments: *this site had an old road bed and small clearing tucked back around the 50 m mark, and is noted on the plots. The complementary site is* NR10.

SITE EIGHT, SR8:
Township 13 North, Range 15 West, sec 12, elevation 4080 ft., edge cut 1982
Southern orientation @ 180°, aspect =0, slope = <5°, edge length = 120 m.
Upper canopy: PIPO/PSME, middle-lower canopy: PIPO. Sampled: 9/27/99
Comments: *this site has the complementary plot* NR11 *across the road.*

SITE NINE, SR9:
Township 13 North, Range 15 West, sec 12, elevation 4200 ft., edge cut 1982
Southern orientation @ 198°, aspect =0, slope = <5°, edge length = 150 m.
Upper canopy: PIPO very open, middle-lower canopy: none. Sampled: 9/29/99
Comments: *this site has the complementary plot* NR12 *across the road. It is a very open ponderosa pine stand.*

SITE TEN, NR10:
Township 13 North, Range 15 West, sec 24, elevation 5000 ft., edge cut 1986
Northern orientation @ 358°, aspect = SW, slope = ~5°, edge length = 140 m.
Upper canopy: PSME sparse, middle: PSME/PIPO thick, some LAOC. Sampled: 9/27/99
Comments: *this is the complement to site* SR7, *and has similar general characteristics.*

SITE ELEVEN, NR11:
Township 13 North, Range 15 West, sec 24, elevation 5000 ft., edge cut 1982
Northern orientation @ 358°, aspect = SW, slope = ~5°, edge length = 140 m.
Upper canopy: PSME sparse, middle: PSME/PIPO thick, some LAOC. Sampled: 9/27/99
Comments: *this is the complement to site* SR7, *and has similar general characteristics.*

SITE TWELVE, NR12:
Township 13 North, Range 15 West, sec 12, elevation 4200 ft., edge cut 1986
Northern orientation @ 18°, aspect =0, slope = <5°, edge length = 150 m.
Upper canopy: PIPO very open, middle-lower canopy: none. Sampled: 9/29/99
Comments: *this site has the complementary plot* SR9 *across the road. It is a very open ponderosa pine stand.*

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